Design of directional couplers for marine applications with artificial transmission lines

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Abstract. The article describes the design of the coupler for marine applications, on which the miniaturization of its dimensions was carried out. The description of the compact device is given. It consists of artificial transmission lines of the original form. The use of such lines for the coupler allowed to achieve good results in reducing the size. So the area of the resulting device is 72.25% less than that of a conventional device, while it has comparable characteristics. The described approach can be used for other devices requiring miniaturization and implemented on a printed circuit board.

1. Introduction

As an object of research, a directional coupler with a wide bandwidth was chosen, designed to separate the input signal between the device outputs. These taps can be used in marine communication systems and other systems. The coupler under consideration is made on the basis of quarter-wave sections, which were then replaced by artificial lines. With all the undeniable advantages of taps, they have a number of disadvantages, among which are their large dimensions. Currently, many specialists are working on miniaturizing such devices. The aim of the work is to reduce the dimensions of the coupler, namely, to develop artificial line circuits based on inductance and capacitance and to install them instead of standard lines. The relevance of miniaturization increases when devices operate at low frequencies. The most common coupler is an eight-pole, assembled in four sections. This design is easy to calculate, configure and manufacture. If it is necessary to expand the strip, add additional segments along the device with a quarter wavelength interval. This allows you to significantly expand the band, but at the same time increases the area that the device occupies. By applying a signal to any of the inputs, you can obtain identical characteristics, since the coupler is a balanced device. Depending on the ratio in which the power should be divided between its outputs, the values of the wave impedances of the segments used in the design of the device depend. When the two outputs have gains of 3 dB, this means an equal division of the input power. In addition to splitting the signal, the coupler can add two signals to two different inputs. For acquaintance with the existing developments in the field of miniaturization, some works [1] - [20] were studied. In our work, using artificial lines, it was possible to achieve good results in miniaturization of a broadband coupler. Table 1 shows a comparison of known miniaturization techniques.

Table 1. Miniaturization methods efficiency.

	Miniaturization methods	Reduce size, %	Center frequency, GHz
	Conventional microstrip line	100	-
[1]	Bending line	56	3.25
[5]	Symmetric Equivalent Circuits	50	1
[6]	Two-layer substrate with rectangular slots in the ground plane	38	2.45
[9]	Source-load coupling	30	2.4
[11]	Artificial line segments	25	0.9
[12]	Asymmetric π-structures	24	0.9
[13]	High impedance lines and loops	19	0.9
[15]	Artificial transmission line	10	1
[16]	Periodically capacitive load	49	1.8
[17]	Asymmetrical T-shape structures	45	2.4
[13]	Equivalent Structures	31	1.8
[12]	Electrodynamic structures	30	1.8
[2]	Compact Structure	30.1	1
[3]	Artificial transmission line	28.1	1
[18]	Quasi-lumped elements	27.5	0.9
[4]	Artificial transmission line	27.5	1
[21]	Fractal technique	24.7	2.4
[10]	Compact Structure	24.7	1
[7]	Artificial transmission line	21.2	0.9

2. Design

In order to assemble a standard coupler, quarter-wave lengths were calculated. After that, they are installed in their places in the device. The result is a square assembled on two stubs. However, in our case, five loops are used to expand the bandwidth. A model of such a coupler is shown in figure 1. Such a coupler fulfills the condition of equality of signals at its outputs in a wide frequency band, while the remaining output will be decoupled. The substrate material is FR4 with a thickness of 1 mm. The operating frequency of the device is 1 GHz. According to the received characteristics of the device, it can be judged that it operates in the frequency band 600-1200 MHz. Moreover, its area is 6942 mm^2. The transmission factors are divided with a phase difference of 90 degrees and have values of 3.3 and 3.8 dB.

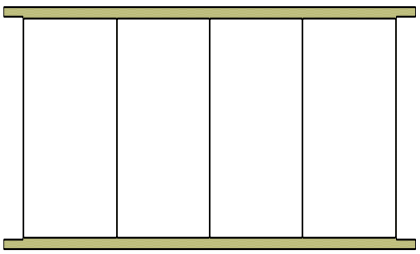

Figure 1. Standard Broadband Coupler Topology.

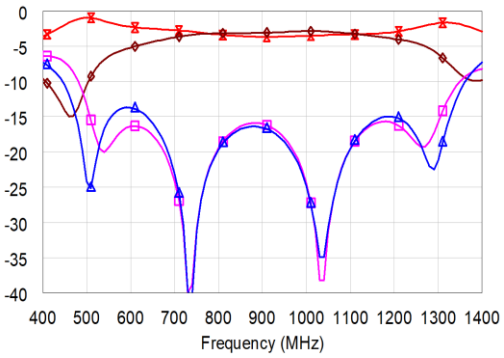

Figure 2. Divider S-parameter plot.

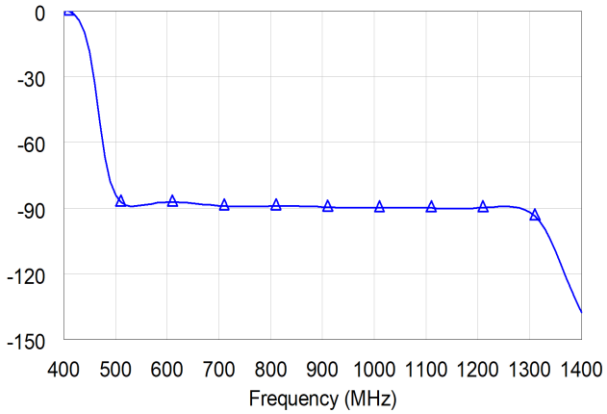

Figure 3. Divider phase difference graph.

3. Materials and methods

Deceleration of an electromagnetic wave is performed using artificial lines. With a shorter length, it is possible to maintain the desired phase. It is due to this that it is possible to carry out miniaturization. After all, the characteristics of conventional and artificial lines at the central frequency have identical values. For low-resistance segments, the calculation of such artificial lines was performed, as shown in figure 4. A comparison of the characteristics of such lines is also carried out, shown in figure 5.6. The substrate material is FR4.

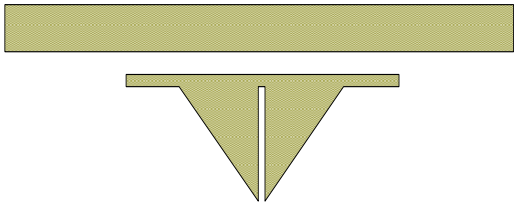

Figure 4. Comparison of the dimensions of conventional segments and artificial transmission lines.

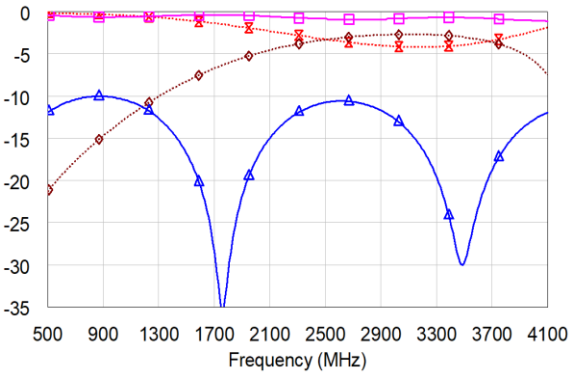

Figure 5. S-parameter versus frequency plot for conventional and artificial transmission lines.

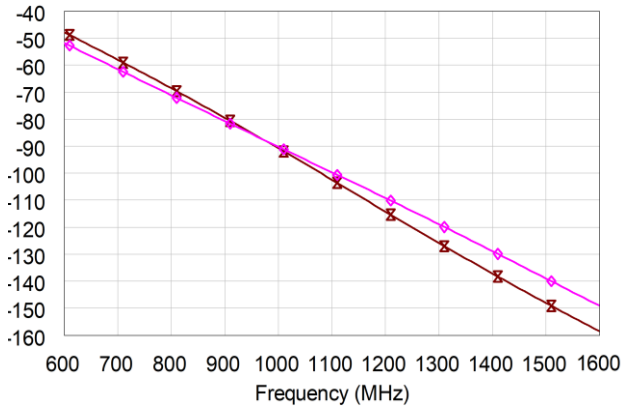

Figure 6. Phase incursion of conventional segments and artificial transmission lines.

4. Results

The comparison results show that artificial lines have smaller dimensions with similar characteristics in a certain band. It is also worth noting that it is not difficult to implement an artificial line in practice. This indicates the success of their application as a tool for miniaturization. High-resistance sections are easier to bend and thereby reduce the area of the device. The compact coupler can be seen in figure 7, its area reaches 2445 mm^2. The characteristics are shown in figures 8 and 9.

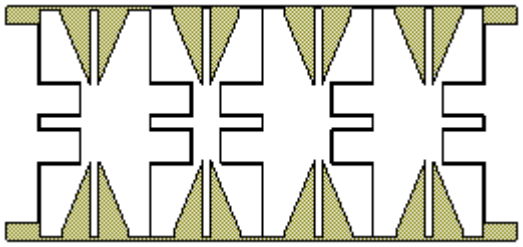

Figure 7. Compact divider.

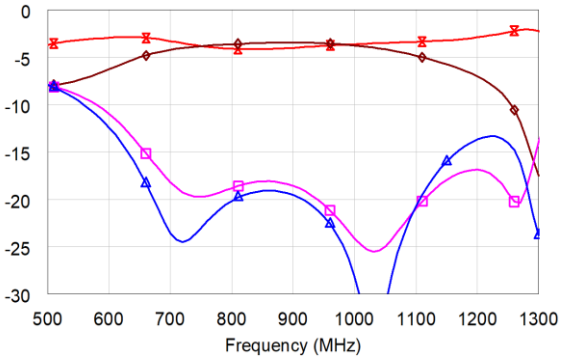

Figure 8. S-parameter versus frequency for a compact coupler obtained in AWR.

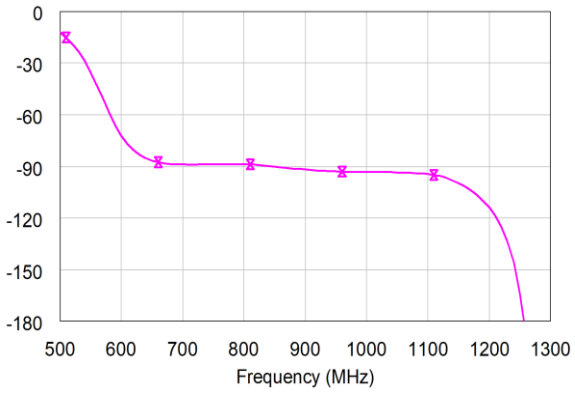

Figure 9. Phase difference between gear ratios at the bridge output.

According to the received characteristics of the device, it can be judged that it operates in the frequency band 660-1150 MHz. The gains are divided with a phase difference of 92 degrees and have values of 3.4 and 3.9 dB. The discrepancy in the characteristics can be described by the phase discrepancy of the lines at farther frequencies from the center frequency. To compare the results of miniaturization, table 2 was presented.

Table 2. Comparative data of tappers.

Parameters	Area, mm^2	Reduce size, %
bandwidth, MHz	600	490
area, mm2	9880	2445
Relative area, %	100	24.75
Central frequency, MHz	900	900
The phase outputs, ^{o}	90	91

5. Conclusion

Artificial transmission lines were used as part of the investigated directional coupler in modern maritime communications. This made it possible to reduce the area of such a device by 75.25%, which is a good result, with a small loss in performance. The artificial lines described in the work can find their application in other taps and devices on a printed circuit board.

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